Presentation at Water Boards WQCC Meeting in Sacramento on October 24, 2013

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1. I am going to give a brief summary of important recent results in the physical science of climate change. Here is Charles David Keeling's celebrated graph showing how the amount of carbon dioxide in the Earth's atmosphere has changed over the last 55 years. Keeling discovered a seasonal cycle in atmospheric CO_2 and proposed that plants caused it. That is the annual oscillation on the graph. CO_2 concentrations were largest in northern spring, when most plants begin to grow, and photosynthesis converts the carbon in CO_2 to plant material, thus lowering atmospheric CO_2 levels. Keeling also discovered the increase in atmospheric CO_2 from year to year. This graph of rising average atmospheric CO_2 amount, from 1958 on the left to the present on the right, is now known as the "Keeling curve." It is the most famous graph in Earth science. Keeling also showed that the primary cause is the burning of fossil fuels: coal, oil and natural gas. All discussions of global climate change due to human activities start with this solid empirical evidence. The Keeling Curve had begun in 1958, when the number was about 314, here at lower left. This number is how many CO_2 molecules there are in a million molecules of air. In 2013, the number approached 400, at upper right.
2. Every 5 or 6 years, for the last 25 years, the Intergovernmental Panel on Climate Change, or IPCC, has organized large international teams of scientists, to review the published technical research literature and produce a thorough and careful assessment of the current state of climate change science. IPCC issued its most recent report in September 2013. This report took hundreds of authors and reviewers three years to write. It is over 2,000 pages long. Some of you may want to read every word of it. For those who don't, I have summarized the entire 2,000-page report in just 12 key points on only two slides. Here's the first slide. **It's warming**. Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.

The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the amounts of heat-trapping gases have increased. Over the last two decades, the Greenland and Antarctic ice sheets have been shrinking, glaciers have continued to melt almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued decreasing.

It's us. Human influence on the climate system is clear. This is evident from the human-caused increasing amounts of CO_2 and other heat trapping gases in the atmosphere, and from the observed warming, and from our deepening understanding of the climate system. Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in average sea level rise, and in changes in some climate extremes. Human influence has been the dominant cause of the observed warming since the mid-20th century.

It hasn't stopped. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was probably the warmest 30-year period of the last 1400 years. I'll show a relevant graph in just a few minutes.

The heat is mainly in the sea. Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated since 1971.

Sea level is rising. The rate of sea level rise since the mid-1800s has been larger than the average rate during the previous two thousand years.

Ice is shrinking. Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent.

3. **CO_2 is making the ocean more acidic**. The ocean has absorbed about 30% of the CO_2 we have emitted into the atmosphere. This has made the ocean significantly more acidic.

   CO_2 in the air is up 40% since the 1800s. From analyzing air trapped in ice, we know what the amount of CO_2 was in the past. It's 40% higher now than in the 1800s, mainly from fossil fuel burning but also from other human activities, such as deforestation.

   It's now the highest in 800,000 years. The ice record goes back many thousands of years. The atmospheric amount of CO_2 has now increased to a level unprecedented in at least the last 800,000 years.

   Cumulative emissions set the warming. Continued emissions of heat-trapping particles and gases will cause further warming and changes in all components of the climate system. Much of the CO_2 that human activities emit into the atmosphere remains there for centuries, before it is removed by natural processes. Therefore, it is our cumulative total emissions of CO_2 that will largely determine global mean surface warming by the late 21st century and beyond.

   Reducing emissions limits the warming. Limiting climate change will require substantial and sustained reductions of human-caused emissions of heat-trapping particles and gases, including CO_2.

   Climate change will last for centuries. Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2.

4. Recently, human-caused climate change has been widely discussed and debated. You will hear people say that global warming has stopped or paused. That's simply not true. You have to keep several facts in mind. One is that over 90% of the heat added to the climate

system by human activities goes into the ocean, and we measure the heat content of the ocean continuing to increase. We also observe changes such as shrinking ice and snow and rising sea level, all of which are continuing. If you look *only* at the average temperature of the lowest layers of the atmosphere, *that* is nudged up and down slightly every year by factors such as El Niño and volcanoes and changes in the sun. Because of this natural variability, we don't expect each year to be warmer than the year before, just as the stock market isn't higher every year, although the long-term trend is upward. To see the trend in temperature, we should average over a decade or two. This graph of average atmospheric temperature shows that each of the last three decades, the three bars at the upper right, has been the warmest decade since measurements began in the1850s.

5. Here's a useful metaphor. Carbon dioxide is the steroids of the climate system. Why? Think about it. You watch a batter on steroids hit a home run. Did the steroids *cause* that particular home run? Wrong question. You can't say they *caused* it, because he was already a big-league slugger when he was clean. Also, he will still strike out sometimes now when he's on drugs. But at the end of the season, you see in his statistics that he hit more homers when on drugs than he used to when he was clean. So the drugs increase the odds. In climate, you can ask, did climate change cause Hurricane Sandy? Wrong question. CO_2 has changed the odds, because climate change has altered the environment in which weather occurs. Hurricane Sandy formed in a world with higher ocean temperatures, increased sea level, more water vapor in the air, and so on, all because the climate has changed. All these factors increased Sandy's potential to do damage. In a similar way, if the climate were not warming, we would expect to see as many new low temperature records set as high ones. But many more high temperature records are being broken now than low temperature records, because the climate is warming. Thus, what we see is a combination of natural variability, plus the odds being changed by a warming caused mainly by CO_2. Climate is simply the statistics of weather, and CO_2 is the steroids of climate.
6. Climate change is not a topic for the far future. It is happening here and now. There is a long list of implications. The consequences include major threats to agricultural productivity as patterns of rainfall change and as heat waves, floods, droughts, and other

examples of weather extremes become worse. People and infrastructure along shorelines and in low-lying areas are threatened by sea level rise. River systems fed by glaciers are directly threatened. The US military regards climate change as a threat multiplier, one that can create environmental refugees and destabilize governments. An ice-free Arctic is one more ocean to patrol. In order to have a chance of holding climate change to tolerable levels, it is urgent that globally large carbon dioxide emissions reductions happen quickly. The urgency has nothing to do with politics or ideology, but is a result of the physics and chemistry and biology of the climate system. We scientists have known about it for a long time. The quote on the slide is from a scientific paper published in 1978, showing that limiting CO_2 increases to moderate amounts required that our emissions peak and start to decline early in the 21st century. However, in the 35 years since this paper, human emissions of carbon dioxide and other heat-trapping gases and particles have continued to increase globally. They have not yet peaked and started to decrease. The warming that results depends on the total cumulative emissions, so we are sentencing our descendants to ever-increasing amount of climate change. The more we allow the average temperature to rise, the worse the consequences will be. Atmospheric temperature rise is just a symptom of climate change, of course. As you know, there is not a magic cholesterol number, such that if your cholesterol level is below it, you're safe, and if it's above it, you'll get a heart attack for sure. Instead, the higher the number, the greater the risk. How lucky do you feel? The larger the CO_2 amount, the greater the risk of tipping points and harmful climate change. Emissions choices that we make now will determine the climate that our children and grandchildren will inherit. My own views on what humankind should do are informed by science but also depend on my own values. When I am asked what policies I personally favor, as one citizen of the planet who also happens to be a climate scientist, I say that there is no silver *bullet*, but there can be silver *buckshot*. We have powerful technology but lack political will. Thus, I favor a price on carbon, increasing with time, and revenue neutral. I favor a strong program to encourage more affordable renewable energy, I favor development of advanced passively safe nuclear power as a temporary bridge technology, I favor the US taking a leadership role internationally, and I favor a massive research and public education effort. You can find

my writings on this and related topics on my web site. Of course, you may disagree with me. I am a climate scientist and not a policy wonk, but I am convinced that great economic benefits will flow to countries – and states - that lead rather than lag in the transition to a sustainable future.

7. I'll be glad to answer questions. Thank you.